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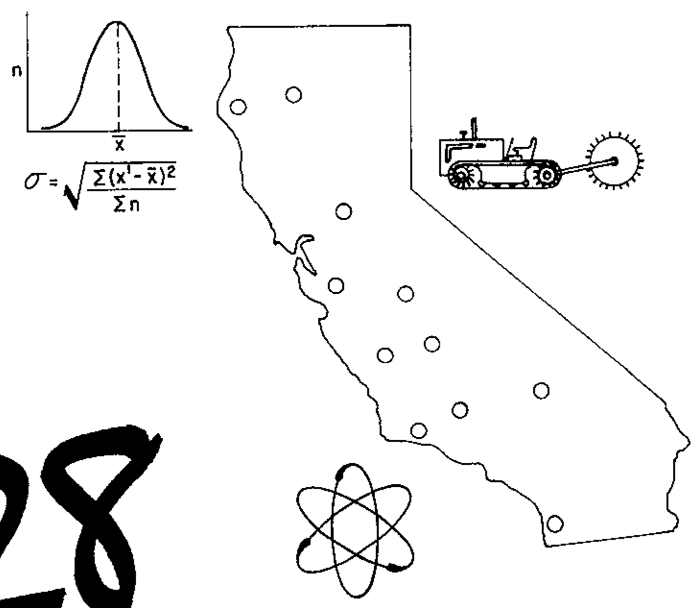

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W. G. Weber, Jr. * and Travis Smith**

Introduction

The art of controlling compaction of embankments in California has varied only slightly since its inception in 1929 (1). However, the rate of placing embankments has increased about tenfold. This increased production rate has made controlling of compaction difficult with the previously acceptable methods. In an attempt to reduce the time required to determine the percent relative compaction the California Division of Highways introduced the "wet method" (2) in 1954, which largely eliminated the necessity for oven drying moisture samples. The use of nuclear surface gages was investigated starting in 1959 to determine the in-place moisture and density of compacted earthwork. (3) As a portion of the field studies with the nuclear gages, statistical studies of the variation in density of compacted earthwork were conducted. In 1964 a study of the density variation within accepted embankments was conducted on three projects (4). As a result of these studies a new test method, using a modified statistical approach and a nuclear surface gage, for compaction control was tried on eleven construction projects throughout the State of California in 1965 and 1966. As a result of this and previous studies the California Division of Highways will start routine use of this new test method that incorporates an area concept, nuclear gages and a modified statistical approach on most construction projects. (5)

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Test Method Development

In 1964 a nuclear gage was used to control earthwork compaction on a project in the north coastal area of California Highway District 01. On this project the test method specified that multiple testing was to be used. That is, several tests were to be made with the nuclear gage at each of several locations in the area to be tested. The individual nuclear test just below the average value of all the tests was used to compute the relative compaction. The acceptance or rejection of an area was thus dependent upon the average of several nuclear in-place density tests. On this project the number of tests in a given area varied from two to fifteen. The multiple testing concept was intended to compensate for the variation in the results that was indicated by previous work in California[3] when nuclear gages are used. In analyzing the data from this preliminary project[6] it was noted that this average value did not "take account" of the spread or range of the in-place densities. It became apparent that a statistical approach was desirable.

On this project it was found that the accepted embankments, with 90 percent relative compaction requirement, had a range of relative compaction from 80 percent to 106 percent for an average of 95.2 percent and a standard deviation of 4.2 percent. While the majority of the individual tests, and all of the average values, from the passing areas were at or above the minimum 90 percent relative compaction specification for the embankments, it can be seen in Figure No. 1 that there is a small group of substandard values scattered through these areas. These substandard tests represent about 9 percent of the total tests from the passing areas. This compares well with the AASHO Road Test [7] where 8.8 percent of the tests fell below the specification limit.

The test results on the structure backfill, aggregate subbase, and aggregate base on this project show a pattern similar to the embankment tests, as shown in Figure No. 2. The passing areas indicate a range of 88 percent to 108 percent for an average of 99.8 percent relative compaction and a standard deviation of 3.4 percent. There are about 8 percent of the tests, from the passing areas, which fell below the minimum specification of 95 percent.

The three projects reported by Jorgensen and Watkins[(4)] indicated that the range in relative compaction was 87 to 98; 85 to 97; and 80 to 103 percent with averages of 92.9; 90.5; and 93.6 percent and standard deviations of 2.4; 3.1; and 5.5 percent. These tests were all from areas accepted by the present sand volume test method. This study confirmed the findings on the first project where a nuclear gage was used for construction control.

The distribution curves for the averages of embankment and processed material are shown in the lower halves of Figures No. 1 and 2. It is to be expected, that the passing area will only extend from the relative compaction specification limit upward, since the failed areas are normally reworked and retested until they too become passing areas. However, it should be pointed out that this does not present an entirely true representation of the probable final state of compaction. Only a very small portion of the total volume of the soil had been tested, and it would be expected that some areas not tested would be below the relative compaction specification limit.

It was felt that there were two advisable ways of modifying the multiple testing procedure which would tend to minimize the chance of including substandard compaction in the final product. First, there should be some limitation placed upon the percentage of failing tests which can be allowed within an area having a passing average and still have the area acceptable. Secondly, there should be some measure of control on the spacing and minimum number of individual test sites within an area.

The first modification, number of failing tests allowed in an area, was determined by studying all of the available data on the in-place density variation in acceptable compacted fills. In the work reported by Jorgensen and Watkins[4] the percentage of tests below the specified minimum relative compaction varied from 8-1/2 to 43 percent. A review of the AASHO test road compaction data indicated that 8. 8 percent of the tests were below the specified relative compaction, in acceptable areas. The report of F. J. Davis [8] in 1953 indicated that 10 to 25 percent of the tests in acceptable areas in dam construction were below the specified relative compaction. The ideal situation would be where the type of material determined the percentage of failing tests, since the percentage of failing tests should be lower with more uniform material. However, this would be difficult to determine in advance of construction.

These variations of in-place density represent the variation within the compacted soil mass and the variation in the sand volume test procedure. Previous work in California indicated that the nuclear test method had a larger variation than the sand volume when used to determine in-place density. [3] Considering all these variations, it was decided that in order to obtain the same compaction as at present, not more than one-third of the individual tests in any area should be below the specified minimum relative compaction.

The second modification, the location and number of tests, was decided on the basis of statistics. The number of tests required for 95 percent confidence level on acceptance or rejection for an estimated average area to be tested was five or six tests. (9), also Appendix A) With the one-third failing requirement it was decided to use six individual tests per area. For the location of the tests, standard control practices in industry and the recommendations of Miller-Warden Associates[10] were studied. As a practical matter it was decided to use a basic unit as an area to be accepted or rejected. This area is then divided into two or more subareas of approximately equal size. Two or more nuclear tests are to be taken in each subarea. The locations were selected at random. It was felt that the above would allow flexibility of action by the resident engineer in controlling compaction, and still retain the basic elements of statistical concepts. This new testing concept was called the "area concept" and was worded in the test method somewhat as follows:

> NUMBER AND LOCATION OF NUCLEAR TESTS
>
> The nuclear test will utilize the area concept. That is, a series of tests will determine whether to accept or reject an entire area. Perform six or more nuclear tests in each area. The engineer shall determine the area based on uniformity of factors affecting nuclear testing.
>
> Divide the area into two or more subareas of approximately equal size. Perform two or more nuclear tests upon each subarea with the locations of the nuclear tests being of a random nature. (For special cases one subarea may be tested with three nuclear tests and considered an area). Determine the moisture and density of the soil by the nuclear tests as described elsewhere in the procedure.
>
> Average these six or more tests and perform the maximum density test on the soil obtained from the location of the nuclear test which has a value just below the average value. Determine the maximum density as specified in Test Method No. Calif. 312 for Classes A and B CTB and Test Method No. Calif. 216 for all other treated and untreated soils and aggregates.
>
> Care must be taken that the same soil type exists over the

given area. This is so that the one maximum density test is consistent with the nuclear tests.

Using the maximum density test, calculate the percent relative compaction for each nuclear test. The average of all of the nuclear determined relative compaction tests must be above the required compaction value. No more than one third of the individual tests may be below the required compaction value. If the average of all tests in one subarea fail to meet the required compaction value, this subarea may be failed even though the other subareas may be passed. Thus, either subareas or areas may be passed or failed.

When sufficient maximum density tests have been obtained, a value may be established for a soil type and only perform check maximum densities on that soil type at least weekly.

Discussion of Test Method

It is strongly felt that the following items are necessary in the test method: (1) must be reasonably rapid in obtaining results, (2) must allow the use of discretion and engineering judgment on the part of the resident engineer as to the application of the test method to ensure a satisfactory product, and (3) must be simple and clear in operation so that field personnel need not spend an excessive amount of time in interpreting the results.

The use of nuclear surface gages enables the obtaining of individual tests in five to fifteen minutes. This would mean that a complete set of six tests could be obtained in about one hour. The previous sand volume test method [11] required that a standard compaction test be conducted at each test site, but in the new test method [12] one standard compaction test is conducted for an area. By the use of the average of several standard compaction tests it was felt that a complete area could be tested in about an hour. In general, the success of the use of this test method would depend upon the uniformity of the soil type and the use of the nuclear surface gages. The pilot project in California Highway District 01 had indicated there was every reason to expect successful use of the nuclear gages.

It was strongly felt that discretion and engineering judgment must be retained by the resident engineer. This meant that the test method could not be restrictive as to its application by the personnel on the project. A test method that would cover all contingencies and conditions that may develop on any, or a limited number of, projects would be bulky and difficult to interpret. This could lead to many disputes with the contractor. In order to avoid this restrictiveness, the test method was prepared to act as a guide to the resident engineer and designed to be flexible and adaptable to changing job conditions. It was felt that the brief and generalized statements used would accomplish this desired result. There was consideration given to limiting the size of an area to be tested. In reviewing the data from the District 01 pilot project, it was found that up to three miles of subbase was tested using fifteen individual tests. It was felt that the size of the area should be left to the discretion of the resident engineer. The only limitations on the size of the area to be tested was to reduce the number of individual tests to three where limited areas such as pipe pads, and structural backfill was being tested.

There was a strong feeling that the test method should avoid technical and complicated procedures. In normal statistical work a table of random numbers would be used; however, this is time consuming and requires additional training. To avoid or minimize operator bias the system of subareas was used. This distributed the tests over the entire area. The selection of at least two individual test sites in a subarea would allow some bias in the individual test site selection. However the need to randomize the testing was stressed, and the remaining potential bias was considered a slight risk. The acceptance or rejection must be in clear and concise terms. The statistical procedures being used in industry could not be applied to earthwork due to the lack of control over the original materials. To provide a quick and simple method of determining acceptance or rejection two simple guides were used: (1) the average value and (2) the permissible percent of the total tests below the accepted minimum. Consideration was also given to using an absolute minimum, that is where any one individual test was below this relative compaction it would result in rejection of an area. However, it was felt that this was an unnecessary addition to the acceptance or rejection criteria.

Field Use of the Test Method

After reviewing all of the previous work in California with nuclear gages, and related compaction studies, it was decided to use nuclear gages in an experimental program using five transmission gages and five backscatter gages. The new area concept was specified as the method of accepting or rejecting the compacted earthwork, by specifying the Test Method No. Calif. 231-B in the special provisions. This is a cooperative project undertaken with the U. S. Bureau of Public Roads and is federally financed with the one and one-half percent research funds.

This research program was arranged so that nuclear gages were used on eleven projects in ten of our highway districts during the 1965 and 1966 construction seasons, with a few projects to be completed in the 1967 construction season. This provided a broad range of various soil types, terrain, climatic conditions and construction operations which represents a cross-section of typical situations normally encountered in California highway construction. Quantities of embankment and structural section material varied from about one-fourth to fifteen and one-half million cubic yards per project.

Thus the nuclear gages are required to check compaction compliance on a total of over 45 million cubic yards of material in this program.

Ten nuclear surface soil gages were purchased for this program from four manufacturers and the previously purchased gages used as spare gages. One nuclear gage was to be used on two projects. Of the four makes, two are backscatter type and two are transmission type. Thus, a comparison of the backscatter and transmission type gages was available.

A one-week training course was provided for the resident engineer, a progress tester, and at least two technicians for each project. The course covered basic nuclear physics, health safety, gage operation and the test method concepts.

The resident engineers were responsible for the application of the new test method with regard to the construction aspects of their projects, application of the nuclear gages to the test method, maintenance of weekly health safety records, and considerations of nuclear sources storage and transport. Health safety is governed by regulations administered by the California Department of Public Health. Each operator and the resident engineer was equipped with film badges and dosimeters to monitor exposure to radiation.

The Materials and Research Department accumulated the data records from the projects and was responsible for the data analysis, from the research viewpoint, and preparation of the research reports. We also provided consultation services to the projects on new test method procedures, review of health safety procedures and handled the maintenance and repair of the nuclear equipment.

In order to be in a sound position to make the decision as to furture use of this procedure, it was necessary to evaluate many aspects of the test procedure, the new area concept of compaction control. Items such as practicality and technical credibility of the test method; health safety, training of personnel, technical feasibility and durability of the various nuclear gages; and administrative aspects, employees and contractors attitude, and general problems.

At the present time six of the projects are completed and the remainder will be completed in 1967 or later. Thus, it was felt that sufficient experience had been obtained at the end of the 1966 construction season to make a decision on the future use of nuclear gages as well as the area concept. In January 1966 a meeting of the resident engineers participating in this research program was held. This meeting was concerned with the technical aspects of the new test method and how it was performing in the field. During the month of July 1966, a meeting was held in each district with representatives of the Materials and Research and Headquarters Construction Departments, and the district field and supervisory personnel who were concerned with the program. These meetings were to discuss the general administrative aspects of the new test method and the new functions that the district would be required to assume in relation to the use of nuclear sources. In the fall of 1966 after executive level conferences, the new test method No. Calif. 231 was adopted by the California Division of Highways. [5]

Discussion of Problems and Solutions

A. Calibration of Gages

The test method originally required the field calibration of the gages by comparison with sand volume tests. This resulted in considerable difficulty. These problems revolved around two items: (1) frequent recalibration of backscatter gages with changes on soil types, and (2) the nuclear gages were used to test soils where it was difficult or impossible to perform sand volume tests.

With the backscatter type gages several calibration curves were required on each project. On one project nine calibration curves were used. However, with the transmission gage, one calibration curve was adequate for all of the soils tested on a project. This is in agreement with previous work in California.[3, 13] The solution of this problem will be to specify the use of the transmission type gage. It is calibrated using standard blocks in a central laboratory. If need occurs to check the calibration in the field it may be done with either a large mold or by use of sand volume comparisons.

When it was impractical to obtain sand volume tests, the soil was compacted in a mold. This mold was 18 x 18 x 12 inches in size. In this manner gages were calibrated for soils on which sand volume tests could not be obtained.

B. Site Preparation

It had been anticipated that site preparation for the individual nuclear tests would be one of the major problems.[3] When numerous complaints were received at the start of the program the Materials and Research Department was prepared with numerous tools and devices to aid in site preparation. Even a gasoline power driven device was prepared. The complaints generally were concerned with two conditions: (1) a hard and somewhat clayey soil, and (2) a rocky soil. With the hard soil it was originally time consuming to cut a plane surface by hand, sometimes requiring 1/2 hour or more per test site. The solution to this problem varied considerably. On one project it was found that a motor grader would prepare a satisfactory site, on another a scraper was found to work well. With rocky soils the primary problem was the depressions caused by the rocks that were removed from the soil. This was overcome by compacting native fines by hand into the depressions. There was no general solution obtained to this problem, however the time required for site preparation was reduced to a reasonable amount by various means. The site preparation procedure will thus vary from job to job depending upon soil conditions and the test method must not be restrictive in this respect.

An interesting side issue was that site preparation was a problem on all projects using the backscatter type of gages, and only a problem on one project using the transmission gage. (The site preparation was considered adequate when two readings obtained by rotating the nuclear gage 180 degrees checked each other within about three pounds per cubic foot.) It had been anticipated that the greatest problem connected with the transmission gage would be due to the necessity of drilling a hole in the soil. However, this did not prove to be a problem on any project using the transmission gage. There were two methods used to make the hole in the soil, a driven pin, and a power drill. Both methods were used about equally on the various projects using transmission type gages.

C. Maintenance

A major difficulty that developed in the field use of the nuclear gages was maintenance of the equipment. It had been anticipated that some down time would occur, so a total of twelve gages were on hand to be used on ten projects, thus a total of two spare gages existed. This number of spare gages proved inadequate and about one-third of the time there were no spare gages available.

The experiences in this research program clearly indicate that to maintain a continuous program of testing with the presently available equipment, a spare gage should be available for every three nuclear gages in use in the field, and should be of the same make.

The down-times for individual gages varied from less than one day to one month. The number of down-time occurrences and the total times are shown in Table No. 1. Due to large number of times that the cable was the cause of the nuclear gage being out of service, a spare cable was obtained for each make of gage. The binding of the transmission rod only occurred on one make of gage, where the source was placed underground. The operators then had to handle an unshielded source and this had an adverse psychological effect. This down-time was overcome by weekly cleaning of the transmission rod and guide; however, the psychological effect remains.

The use of backup gages of the backscatter type did not operate successfully, mainly due to the need to calibrate the gage to the soil type. This generally resulted in about a two-day or more delay in getting the gage in operation. After several occasions where recalibration was required for use of the backup gage, the resident engineers using backscatter gages would refuse the use of backup gages. Where a delay of several weeks occurred in repair this became a serious matter. On the projects where transmission gages were used this backup gage problem did not occur. Upon receipt of the backup gage, immediate resumption of testing occurred as the predetermined calibration was of sufficient accuracy.

D. Backscatter-Transmission Comparison

One of the objects of this research program was to compare the backscatter and transmission types of gages in actual field operations. The principle disadvantages of the backscatter gages were the need to calibrate for each soil type and their sensitivity to seating of the gage on the soil surface. Both of these problems have been discussed above. With one transmission gage some difficulty was encountered in aligning the gage over the hole. The other transmission gage had an attachment so that the hole could be seen and the rod easily aligned over the hole. As the result of this research program a specification has been prepared specifying a transmission type of gage with the detector tube placed underground.

E. General Comments on Nuclear Gages

There were many advantages that the nuclear gages had over the previous sand volume test. One major advantage was the ability to test rocky soils that previously we had been unable to test with the sand volume test. On project after project, some of the soils were tested that previously had been accepted upon the basis of inspection. It was estimated that about 20 percent more rocky type material could be tested with the nuclear gage than the previous sand volume test. On only two of the projects was material encountered that was untestable with the nuclear gage, and this was due to the inability to obtain a plane surface to seat the gage on.

There was some time savings on the individual test sites when the nuclear gage was used. With the sand volume test it generally required 1/4 to 1/2 hour per test, and with the six nuclear test sites it generally required 1/2 to 1-1/2 hours. However, these times do not reflect the whole picture. Where dry densities were required the sand volume test would require additional time to take a sample to the project laboratory and dry the sample. This is where the real time savings was on many projects. The ability of the nuclear gage to give an answer in the field without further work was a decided advantage.

An important item from the contractor's viewpoint was the fact that he was not required to stop the equipment during the nuclear test. With the sand volume test all equipment on the fill would have to stop while the sand was being poured in the hole to obtain its volume. It was quite a sight to see the heavy earthmoving equipment operating at full speed in the vicinity of the nuclear gage.

The decision as to using the power supply supplied with the nuclear gage or to use the vehicle battery for power supply was left up to the resident engineer. On three projects the resident engineer elected to use the vehicle batteries for a power supply to operate the nuclear gages. There were no down-times due to failure in the power supply on these three projects, whereas on the other projects there were significant down-times due to failure of the power supply provided with the gage. For this reason the specifications for the new gages require the use of the vehicle battery as the source of power to operate the gage.

Performance of the Area Concept

At the start of this research program there was considerable concern about the acceptance of the statistical concept. In the training classes there was considerable reluctance on the part of the trainees to accept the statistical concepts; however, the resident engineers were asked to give it a reasonable trial. They were unanimous in accepting this concept after gaining experience in its use. The acceptance by highway and contractors personnel of this new test method was outstanding, and far exceeded our expectations.

It was our intent to require compaction equivalent to that previously obtained. The opinions of the various people concerned was that basically no major change in compactive effort has resulted where the new test method was used. However, this is only an opinion and the best comparison would be a study of how the density varied in the accepted earth work.

The density variation of compacted earthwork on three completed typical projects are shown in Figures No. 3, 4, and 5. Project No. 1 consisted of minor fills and cuts with major structural section work, therefore, only the structural section densities are shown in Figure No. 3. The range of relative compactions was from 84 to 112 percent with an average of 97 percent and a standard deviation of 3.6. There were fourteen percent of the tests below 95 percent relative compaction.

Project No. 2 consisted of small cuts and fills in shales and structural section work and the test results are shown in Figure No. 4. About half of the embankment material was of such a rocky nature that the sand volume test could notbe performed, however, no major difficulty was encountered performing the nuclear tests. The range of relative compactions for the embankment soils was from 77 to 107 percent for an average of 95.6 and a standard deviation of 4.4. There were twelve percent of the tests below 90 percent relative compaction. The material with a 95 percent relative compaction requirement is also shown in Figure No. 4. This material had a range of relative compactions from 89 to 111 percent, for an average of 98.6 and a standard deviation of 3.4. There were eleven percent of the tests below 95 percent relative compaction.

Project No. 3 contained heavy embankment work on soil and rock material and the density distributions are shown in Figure No. 5. About thirty percent of the embankment material would normally be considered too rocky to test by means of the sand volume equipment, however, all soils were testable with the nuclear equipment. The embankment materials indicated a range in compaction of 80 to 114 percent relative compaction with an average of 94.8 and a standard deviation of 4.3. There were 7.5 percent of the tests below 90 percent relative compaction. The material with a specified 95 percent relative compaction had a range of 88 to 110 percent for an average of 97.5 and a standard deviation of 2.8. There were 8 percent of the tests below 95 percent relative compaction.

Distribution plots of the type shown above are maintained on all eleven of the projects in this study, and are similar to the illustrations above. The distributions indicate that the distribution of relative compactions of accepted areas have a higher average value and a smaller percentage of the values below specification limit than was found in the statistical studies in California.(4) This would indicate that the new test method results in a slight increase in the quality of the compaction of earthwork being obtained.

Reaction of District Personnel

The reaction of the district personnel, both in the field and from an administrative viewpoint, was almost complete acceptance. The general feeling was that "Now we know what compaction we are obtaining." The resident engineers were in agreement that no consideration should be given to replacing the sand volume test by the nuclear test while still using one test only for acceptance or rejection. The area concept was what they wanted.

Realizing that the transition to the new test method would require a period of time, two asked that the sand volume be substituted for the nuclear test in the new test method so that more projects could take advantage of the area concept. Considering the opposition at the start of the research program this is truly remarkable.

There was general agreement that the contractors were required to produce about the same work on compacting earthwork as previously. However, it was felt that the contractor was able to make more efficient use of his equipment. The general feeling was that the resident engineers were sure of the quality of the work obtained. The number of areas that had to be reworked appear to be about the same as had been obtained under the previous test method.

The general feeling of the field personnel was that the cost and manpower requirements of the twotest methods were about equal, with any time savings in favor of the new test method. This would mean that there would be no large financial savings to the Division of Highways from the standpoint of testing costs.

All districts expressed concern about the maintenance problems. In the districts where high down times had occurred there was even the suggestion that two nuclear gages be assigned to each project.

There was no reluctance of the districts to undertake the administrative aspects of the nuclear gages. This would include the training, maintenance and health safety programs.

The districts expressed general agreement that the new test method should be used on the high production projects. Some of the districts felt that "fly" parties could handle the smaller projects. The districts all felt that from an administrative viewpoint there should be a gradual transition from the present conventional testing to the new area concept.

Contractors Reactions

At the start of the research program most contractors appeared to be neutral, however, by the end of the program the majority were definitely favorable. The favorable contractors reactions appeared to be based upon three points which are as follows:

The use of nuclear gages enabled the supplying of quick results to the contractor. On several of the projects the contractors foremen would accompany the State personnel making the tests. When a portion of the area would start failing, the method of the contractors operations would be changed. The contractor, on one major project was able to control in less than one day, his method of compaction of base material. Several contractors cite this rapid obtaining of results as being an important factor in their favoring the new test method.

Another item that several contractors favored about the new test method was that it enabled them to more efficiently utilize their equipment. Often a portion of the fill would be below specified compaction and only this portion would need additional compaction. This portion could receive additional compaction while embankment material was placed on the remainder of the fill. Also the contractors often were able to vary compaction patterns so as to obtain a reasonably uniform compaction over the entire fill. The contractors readily accepted the results of the area concept and did not question the rejections as had frequently occurred with the sand volume test method. Several contractors expressed approval of the area concept and felt that it greatly aided in the planning of their operations.

An unexpected item was the contractors reaction to the use of the nuclear gages in relation to their operations. This was that they no longer needed to stop all hauling operations while the sand was being poured during the sand volume test. One contractor estimated that this item alone cost him $25,000 to $50,000 per year. Several other contractors also commented upon this item.

The contractors estimated zero to two cents per cubic yard reduction in cost, depending upon conditions, could be expected when the new test method was adopted. However, the actual savings in construction costs is difficult to evaluate because so many other factors influence the bid prices. his saving may be realized at times; however, it is felt that the estimated dollar savings is somewhat indeterminate at the present time.

Plan of Operation

The implementing of the decision to convert to the new method of compaction control will be a gradual process. That is, the modified statistical test method will be utilized on the larger earthwork projects that are let to contract each year. At first it may be that each highway district could submit to headquarters the projects on which they wish to use the new test method and then the available gages could be assigned to the districts where they will be best utilized. Some of the districts also desire to establish "fly" parties for the smaller projects, which could also be gradually done. It is estimated that three to five years would be required to fully equip the various projects with nuclear gages, depending upon financing.

Each of California's eleven highway districts will be licensed to handle and administer the use of the nuclear gages. This would include the health safety, training, and maintenance aspects of the nuclear gages. The standardization of the test procedure and purchase of the nuclear gages will be handled as a function of headquarters, as on all other testing.

The health safety will be handled by the district safety engineers. They and the licensee are receiving special training. The licenses are being obtained from the California Department of Public Health. They will follow the administrative procedures as set by Headquarters, so that all licenses in the districts will be the same. All health safety and administrative records will be kept at the district level.

The training probably will be obtained by service agreement with an outside organization. The state law requires thorough training in health safety and equipment operation. This will be performed in the various districts as need for trained operators develops.

The maintenance of the nuclear gages will be performed by service agreement. The licensee in each district will be responsible for obtaining the necessary maintenance, and assigning of gages to the individual projects.

The nuclear gages will be purchased by Headquarters for the entire State by bid. The nuclear gages will be of the transmission-backscatter type measuring both moisture and density and will be constructed to the California Division of Highways specifications. It is anticipated that the nuclear gages will be purchased in quantities that would be economical and at the same time consistent with our needs.

The test procedure will be standardized state-wide and revisions periodically made as necessary. The test method will be a part of the California Division of Highways Materials Manual and have the designation Test Method No. Calif. 231.

Conclusions

The completion of seven years of studies and research on compaction control utilizing nuclear gages, a practical test method has been developed. This test method is a modified-statistical method that utilizes nuclear gages to determine the in-place soil moisture and density. A specification for a nuclear gage that will perform satisfactorily has been prepared. It is felt that this new test method utilizating the Area Concept and nuclear gages represents a definite improvement in compaction control.

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(10) A Plan for Expediting the Use of Statistical Concepts in Highway Acceptance Specifications," a report prepared for the Department of Commerce, Bureau of Public Roads, Office of Research and Development, by Miller-Warden Associates, Raleigh, N. C., August 1963.

(11) "Test Method No. Calif. 216-F", California Division of Highways Materials Manual, Testing and Control Procedures, Vol. I.

(12) "Test Method No. Calif. 231-B", California Division of Highways Materials Manual, Testing and Control Procedures, Vol. I.

(13) "A Basic Study of the Nuclear Determination of Moisture and Density," a Materials and Research Department Report, California Division of Highways, Nov. 1965.

TABLE NO. I

Nuclear Gage Malfunctions on State-wide Study

from March 1, 1965 to July 1, 1966

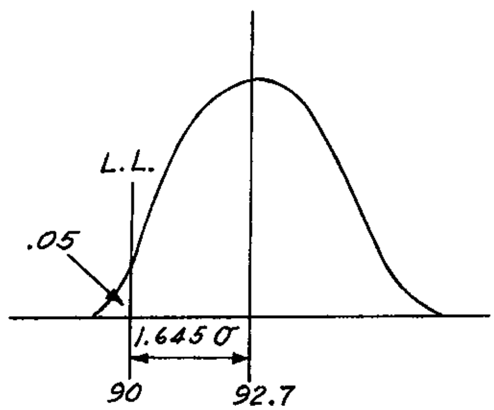
Cause of Malfunction	No. of Occurrences	Working Days Down-Time
1. Scaler	28	184
2. Probe	12	103
3. Cable and/or Connections	18	43
4. Power Supply	4	5
5. Binding of Transmission Rod	5	5
TOTAL	67	340

APPENDIX A

Statistical Determination of Sample Size

__Assumptions__

1. Lower Limit of Specification = 90% R. C.
2. Ave. of all Comp. Results Approx. 92.7% R. C.
   (from earlier studies (-4)
3. Standard deviation of process + 4% R. C.
4. Probability of .95



$$\sigma_{\bar{x}} = \frac{2.7}{1.645} = 1.64$$

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

$$\sqrt{n} = \frac{\sigma}{\sigma_{\bar{x}}} = \frac{4}{1.64} = 2.44$$

$$n = (2.44)^2 = \underline{\underline{5.96}}$$

Use sample size of 6

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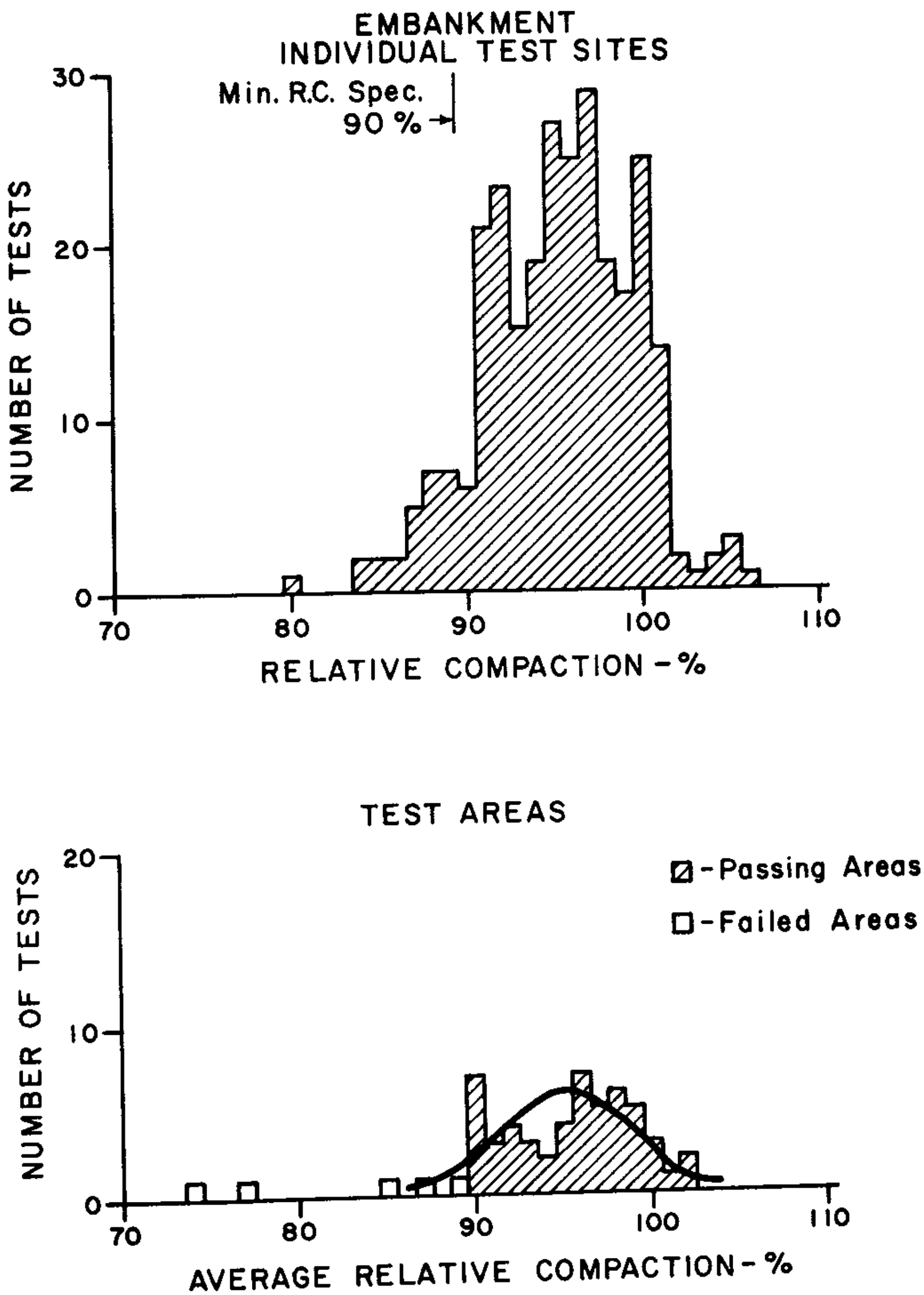
FIGURE 1

FREQUENCY DISTRIBUTION
PILOT PROJECT



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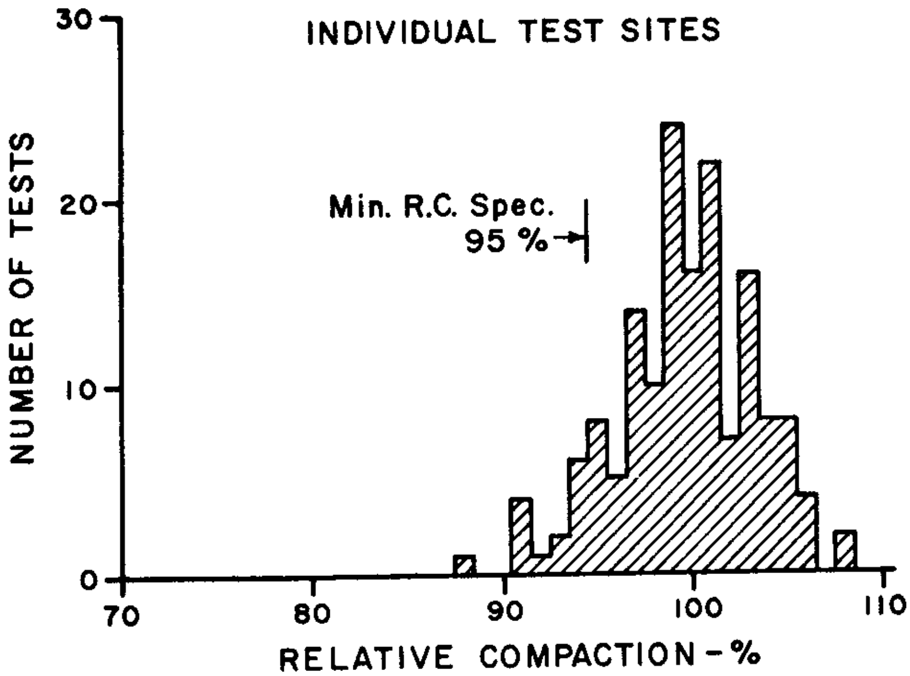
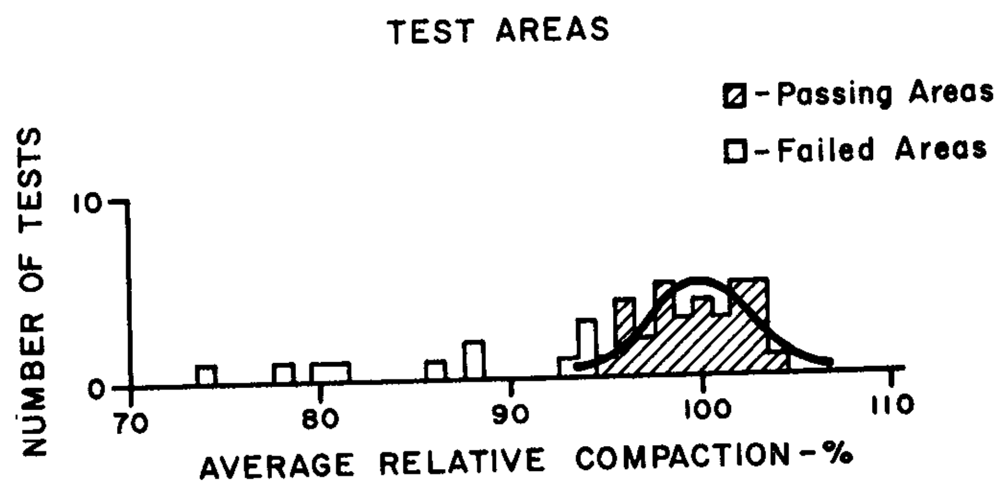
FREQUENCY DISTRIBUTION
PILOT PROJECT
PROCESSED MATERIAL





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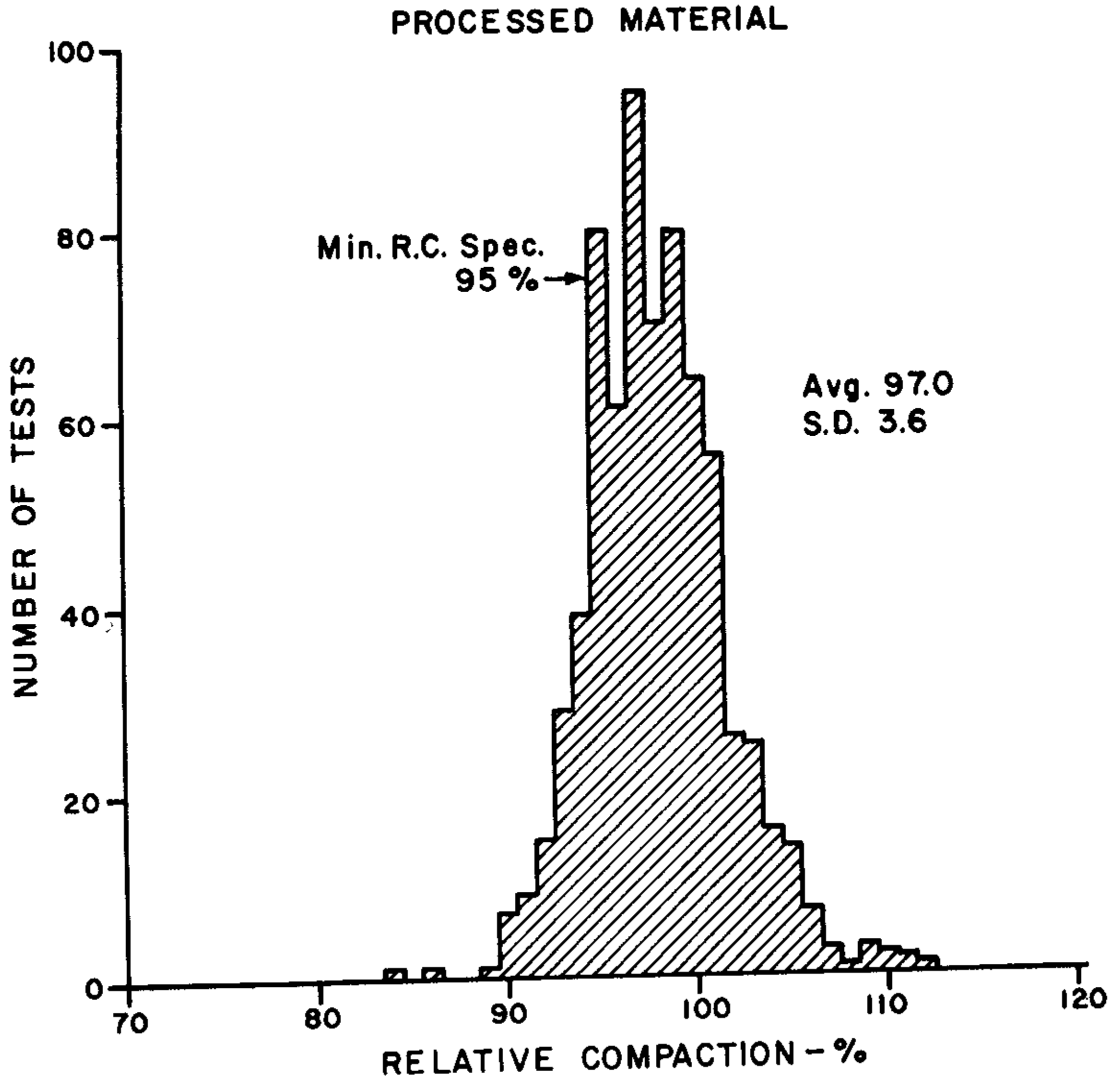
FREQUENCY DISTRIBUTION
PROJECT NO. 1
INDIVIDUAL TEST SITES
PASSING AREAS ONLY



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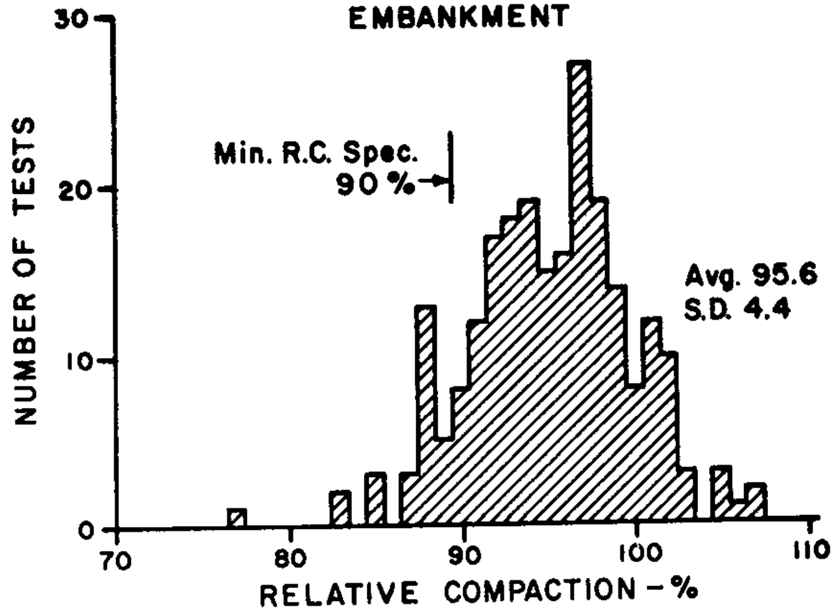
FREQUENCY DISTRIBUTION
PROJECT NO. 2
INDIVIDUAL TEST SITES
PASSING AREAS ONLY



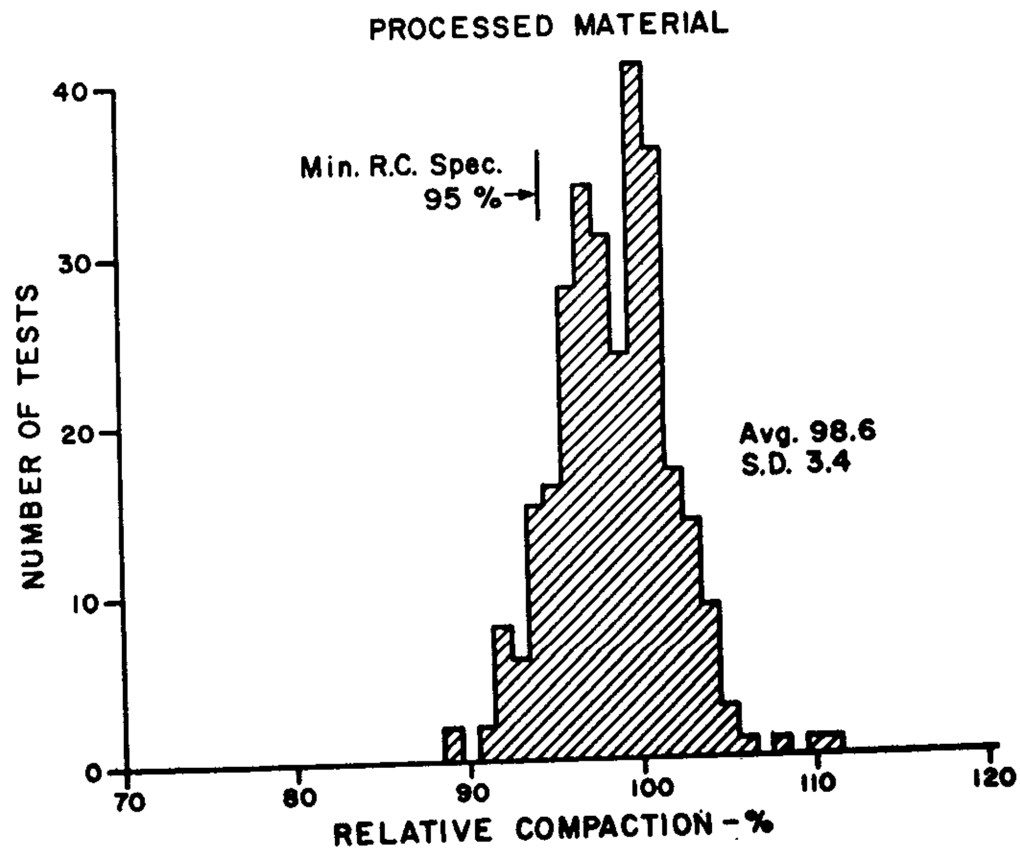


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FIGURE 5

REQUENCY DISTRIBUTION
PROJECT NO. 3

INDIVIDUAL TEST SITES
PASSING AREAS ONLY